Claims

What is claimed is:

[c1] A method for separating energy resulting from actuating at least two different seismic energy sources from seismic signals, the sources actuated to provide a variable time delay between successive actuations of a first one and a second one of the sources, the method comprising:

sorting the seismic signals such that events therein resulting from actuations of the first source are substantially coherent in all spatial directions;

coherency filtering the first source coherency sorted signals;

sorting the seismic signals such that events therein resulting from actuations of the second source are substantially coherent in all spatial directions; and

coherency filtering the second source coherency sorted signals.

[c2] The method of claim 1 further comprising:

subtracting the coherency filtered first source coherency sorted signals and the coherency filtered second source coherency sorted signals from the seismic signals to generate residual seismic signals;

sorting the residual seismic signals such that events therein resulting from actuations of the first source are substantially coherent in all spatial directions;

coherency filtering the first source coherency sorted residual signals;

sorting the residual seismic signals such that events therein resulting from actuations of the second source are substantially coherent in all spatial directions; and

coherency filtering the second source coherency sorted residual signals.

[c3] The method of claim 2 further comprising:

determining whether a value of a parameter in the coherency filtered, first source and second source sorted residual signals exceeds a selected threshold, the parameter related to an amount of energy in a seismic signal;

subtracting the coherency filtered, first source sorted residual signals and the coherency filtered second source sorted residual signals from the residual signals; and

repeating the sorting and coherency filtering until the value drops below the selected threshold.

[c4] The method of claim 3 wherein the parameter comprises peak trace amplitude.

[c5] The method of claim 3 wherein the parameter comprises trace energy.

[c6] The method of claim 3 wherein the parameter comprises average trace amplitude.

[c7] The method of claim 2 further comprising adding the coherency filtered, first source sorted residual signals to the coherency filtered, first source sorted seismic signals.

[c8] The method of claim 2 further comprising adding the coherency filtered, second source sorted residual signals to the coherency filtered, second source sorted seismic signals.

[c9] The method of claim 1 wherein the sorting the seismic signals comprises generating a common channel plane gather with respect to the first source.

[c10] The method of claim 1 wherein the sorting the seismic signals comprises generating a common channel plane gather with respect to the second source.

[c11] The method of claim 1 wherein the coherency filtering comprises slant stack processing.

[c12] The method of claim 11 wherein the slant stack filtering comprises transforming traces into the tau-p domain, excluding portions of the transformed traces corresponding to energy other than a coherency reference, and inverse transforming portions of the traces having the excluded energy into the time-space domain.

[c13] The method of claim 12 wherein the transforming into the tau-p domain comprises performing a Radon transform.

[c14] The method of claim 1 wherein the sorting comprises sorting seismic traces into the common channel/common shot domain.

[c15] The method of claim 1 wherein the sorting comprises sorting seismic traces into the common depth point/common offset domain.

[c16] A method for seismic surveying, comprising:

towing a first seismic energy source and at least one seismic sensor system;

towing a second seismic energy source at a selected distance from the first seismic energy source;

actuating the first seismic energy source and the second seismic energy source in a plurality of firing sequences, each of the firing sequences including firing of the first source and the second source and recording signals generated by the at least one seismic sensor system, a time interval between firing the first source and the second source varied between successive ones of the firing sequences;

sorting the seismic signals such that events therein resulting from actuations of the first source are substantially coherent in all spatial directions;

coherency filtering the first source coherency sorted signals;

sorting the seismic signals such that events therein resulting from actuations of the second source are substantially coherent in all spatial directions; and

coherency filtering the second source coherency sorted signals.

[c17] The method of claim 16 further comprising:

subtracting the coherency filtered first source coherency sorted signals and the coherency filtered second source coherency sorted signals from the seismic signals to generate residual seismic signals;

sorting the residual seismic signals such that events therein resulting from actuations of the first source are substantially coherent in all spatial directions;

coherency filtering the first source coherency sorted residual signals;

sorting the residual seismic signals such that events therein resulting from actuations of the second source are substantially coherent in all spatial directions; and

coherency filtering the second source coherency sorted residual signals.

[c18] The method of claim 16 further comprising:

determining whether a value of a parameter in the coherency filtered, first source and second source sorted residual signals exceeds a selected threshold, the parameter related to an amount of energy in a seismic signal;

subtracting the coherency filtered, first source sorted residual signals and the coherency filtered second source sorted residual signals from the residual signals; and

repeating the sorting and coherency filtering until the value drops below the selected threshold.

[c19] The method of claim 18 wherein the parameter comprises peak trace amplitude.

[c20] The method of claim 18 wherein the parameter comprises trace energy.

[c21] The method of claim 18 wherein the parameter comprises average trace amplitude.

[c22] The method of claim 17 further comprising adding the coherency filtered, first source sorted residual signals to the coherency filtered, first source sorted seismic signals.

[c23] The method of claim 17 further comprising adding the coherency filtered, second source sorted residual signals to the coherency filtered, second source sorted seismic signals.

[c24] The method of claim 16 wherein the sorting the seismic signals comprises generating a common channel plane gather with respect to the first source.

[c25] The method of claim 16 wherein the sorting the seismic signals comprises generating a common channel plane gather with respect to the second source.

[c26] The method of claim 16 wherein the coherency filtering comprises slant stack processing.

[c27] The method of claim 26 wherein the slant stack processing comprises transforming traces into the tau-p domain, excluding portions of the transformed traces corresponding to energy other than a coherency reference, and inverse transforming portions of the traces having the excluded energy into the time-space domain.

[c28] The method of claim 27 wherein the transforming into the tau-p domain comprises performing a Radon transform.

[c29] The method of claim 16, wherein the time interval is varied systematically.

[c30] The method of claim 16 wherein the time interval is varied quasi-randomly.

[c31] The method of claim 16, wherein the time interval varied is randomly.

[c32] The method of claim 16, wherein the time interval is varied in steps of about 100 milliseconds.

[c33] The method as defined in claim 16, wherein the time interval is at least as long as a wavelet time of the first source.

[c34] The method of claim 16 wherein the sorting comprises sorting seismic traces into the common channel/common shot domain.

[c35] The method of claim 16 wherein the sorting comprises sorting seismic traces into the common depth point/common offset domain.

[c36] A program stored in a computer readable medium, the program including logic operable to cause a programmable computer to perform steps comprising:

sorting seismic signals resulting from actuating at least two different seismic energy sources, the sources actuated to provide a variable time delay between successive actuations of a first one and a second one of the sources, the sorting performed such that events therein resulting from actuations of the first source are substantially coherent in all spatial directions;

coherency filtering the first source coherency sorted signals;

sorting the seismic signals such that events therein resulting from actuations of the second source are substantially coherent in all spatial directions; and

coherency filtering the second source coherency sorted signals.

[c37] The program of claim 32 further comprising logic operable to cause the computer to perform:

subtracting the coherency filtered first source coherency sorted signals and the coherency filtered second source coherency sorted signals from the seismic signals to generate residual seismic signals;

sorting the residual seismic signals such that events therein resulting from actuations of the first source are substantially coherent in all spatial directions;

coherency filtering the first source coherency sorted residual signals;

sorting the residual seismic signals such that events therein resulting from actuations of the second source are substantially coherent in all spatial directions; and

coherency filtering the second source coherency sorted residual signals.

[c38] The program of claim 37 further comprising logic operable to cause the computer to perform:

determining whether a value of a parameter in the coherency filtered, first source and second source sorted residual signals exceeds a selected threshold, the parameter related to an amount of energy in a seismic signal;

subtracting the coherency filtered, first source sorted residual signals and the coherency filtered second source sorted residual signals from the residual signals; and

repeating the sorting and coherency filtering until the value drops below the selected threshold.

[c39] The program of claim 36 wherein the parameter comprises peak trace amplitude.

[c40] The program of claim 36 wherein the parameter comprises trace energy.

[c41] The program of claim 36 wherein the parameter comprises average trace amplitude.

[c42] The program of claim 37 further comprising logic operable to cause the computer to perform adding the coherency filtered, first source sorted residual signals to the coherency filtered, first source sorted seismic signals.

[c43] The program of claim 37 further comprising logic operable to cause the computer to perform adding the coherency filtered, second source sorted residual signals to the coherency filtered, second source sorted seismic signals.

[c44] The program of claim 36 wherein the sorting the seismic signals comprises generating a common channel plane gather with respect to the first source.

[c45] The program of claim 36 wherein the sorting the seismic signals comprises generating a common channel plane gather with respect to the second source.

[c46] The program of claim 36 wherein the coherency filtering comprises slant stack processing.

[c47] The program of claim 46 wherein the slant stack filtering comprises transforming traces into the tau-p domain, excluding portions of the transformed traces corresponding to energy other than a coherency reference, and inverse transforming portions of the traces having the excluded energy into the time-space domain.

[c48] The program of claim 47 wherein the transforming into the tau-p domain comprises performing a Radon transform.

[c49] The program of claim 36 wherein the sorting comprises sorting seismic traces into the common channel/common shot domain.

[c50] The program of claim 36 wherein the sorting comprises sorting seismic traces into the common depth point/common offset domain.